STUDY OF OCEAN WAVE ENERGY IN AN OPTIMUM WAVE TANK WITH A PLUNGER TYPE WAVEMAKER

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List of Acronyms

SYM	Scotch Yoke Mechanism
SWP	Statistical Wave Period
VFD	Variable Frequency Drive
SAO	Sensitive Amplitude Operator
PTO	Power Take Off
WEC	Wave Energy Converter

Acknowledgements

First and foremost, we would like to thank the Almighty for helping us through our journey at the Islamic University of Technology. We are grateful to our supervisor Dr. Md. Hamidur Rahman for his support, guidance and encouragement throughout our study at this wonderful institution. We would also like to thank our faculty members and staff for their support and hard work. It has been an honour to be a part of this amazing journey. Each of us would like to thank our project partners for the brilliant effort everyone put in towards the completion of this project.

Finally, we would like to thank our parents, friends and well-wishers for their continued love and support without whom none of this would have been possible.

Abstract

Renewable energy technology that can operate to rival with conventional energy sources at a monetary elevation. A wave power utensil comprises an energy harvesting strategy. Our Project provides the distinctive and revolutionary approach to pull out energy from ocean energy to generate electricity using the energy dissipation principle. Our research is based on the development of a device that can extract energy from stringy different wave forms as electrical energy. Our thesis implies that initial data have already been yielded indispensable information and also been performed to signify the successful scheme and functionality of the channel included with data logging test bed. Our experimental test bench of energy extraction process implemented by the particles of water flow adopted by the up and down lifting plunger as part of the wave. This improved motion that actually extracted energy being converted to kinetic energy. The amount of energy has been disclosed to the RPM and duration of generating wave. An electrical appliance and mechanical erection have been provided for generating wave results as energy mathematical solutions through a buoyed channel based on power input system. This experiment shows rhythmic, dynamic surface waves corresponding to a sinusoidal curve which is commensurable around the equilibrium water. Its feasibility has been investigated by coupling the dynamics of the wave motion and phase velocity.

Chapter 1

Introduction

Wave energy has been transformed including with higher energy and lower energy conservation by generating wave. From the beginning of introducing with renewable energy demand Researchers were concerned of hydro power that has already been recommended differential mechanical and electrical instruments such as wave generating tank on promoting wave power for human mankind, such as disaster like unexpected tsunami suppressant and definitely it had an adorable initiative of wave suppression system. This research paper aims to build up a relationship between wave height and energy deformation. Developed wave energy is converted into kinetic energy in such a way which defines the phase velocity as interactive to the sinusoidal curve.

Firstly wave tank has been formed by celluloid sheet which functions as two dimensional parameters. Wave got stroke including scotch yoke mechanism (SYM) system defined as up and down lifting plunger. Plunger has been submerged to the wave tank transversely. DC motor has been set up which is directly connected to the lifting mechanism previously defined as up and down plunger. Then rapidly irresolute lifting plunger converted the electrical input into mechanical output which has been formed as energy dissipation on differential values of wave characteristics. Tachometer has been used to find out the number of stroke (RPM). A 30 degree angled slope has been submerged inside the wave tank to figure out the reflected wave parameters.

Theoretically and experimentally it had been demonstrated that when waves are in a motion could be twisted into not linear or even regular form. A reference model had been implemented of sustainable energy to take possession of marine and hydrokinetic innovation including reciprocating mechanism and wave energy converters. This project defined the potential cost of energy and identifying cost reduction. This report provided experimental data sets for validating numerical analysis of wave tank tests [2]. (Falcao, 2010) implied that research in assembling power generation using wave energy had been proposed and treated as undertaken. Another research paper has aimed to develop more accurate approximation methods by utilizing a number of available parameters. Generated wave data has been effectively measured to evaluate the wave energy resource including with the effects of finite water depths. The distributed wave energy [1-4] level from where national wave energy resources have been determined [5-14] to provide valuable information related to global wave energy resource. From the resulted information it has been investigated that the global offshore wave power is estimated at 32000 TWH/year [2]. Wave energy resources also been determined significantly.

The total power of waves have been investigated around the world's coastlines is estimated 2-3 megawatts. The west coasts of United States and Europe and the coasts of Japan and New Zealand are going through positive sites for harnessing wave energy [17].

Wave energy extraction process has gained a sustainable energy resource. Appropriate devices have been used to convert mechanical energy to electrical energy. Mechanical energy carried out to wave energy. Wave energy deformation has been calculated by converting mechanical energy to wave energy through power take off system (PTO).

Our project should be implemented for extracting wave energy and that energy will be converted into demandable electricity generation. Justifying the total energy conservation it has become a remarkable issue to utilize the method of generating wave parameters which scrupulously corresponded to sea conditions.

1.1 Different Aspects of Wave Energy

Wave power is a much-neglected source of renewable energy. More consistent and reliable than wind, it is suffering badly from lack of investment. Wave tank was built for measuring the effects of wave on the on both the on shore and off shore areas. The term wind sea is used for waves that are actively growing due to forcing from local wind. These waves travel in or close to the local wind direction. Swell is the term used to long-period waves that have moved out from the storm area where they were generated. Swells spread out over the ocean with little energy loss. They are somehow analogous to waves spreading out from the splash of a stone thrown into a pond. Swells in deep water will, typically, have wavelengths of 100–500 m whilst wind seas may range from a few meters to 500 m depending on the wind speed. In this context, deep water is understood to mean that the water depth exceeds about one third of the wavelength. Then the seabed has a negligible influence on the wave. An instantaneous picture of the ocean offshore will generally reveal several wave trains with different wavelengths and directions. Swells may coexist with wind sea. In contrast to a single-frequency sinusoidal wave propagating in a particular direction, a real sea wave may be considered as composed of many elementary waves of different frequencies and directions.

The variability of wave conditions in coastal waters is, generally, very large compared to offshore waters. Near-shore variation in the wave climate is compounded by shallow-water physical processes such as wave refraction, which may cause local ‘‘hot spots’’ of high energy due to wave focusing particularly at headlands and areas of low energy in bays due to defocusing. In addition, other coastal wave processes such as wave reflection, diffraction, bottom friction and depth-induced breaking effects may have some influence. As averaged over years, offshore wave-power levels in the range of 30–100 kW/m are found at latitudes 40–501, and less power levels further south and north. In most tropical waters, the average wave-power level is below 20 kW/m. Offshore wave-power levels may vary from a few kW/m during calm weather to several MW/m during storms. Wave-power levels will vary over time, on many different time scales: hours (104s), days (105s), weeks (106s), months, seasons (107s) and years (108s). There are also important wave variations on shorter time scales: wave periods (101s) and duration of and intervals between wave groups (102s). In spite of their importance, information on wave groups are not always taken care of by wave spectra obtained from wave records (during 103 s). Availability of time series, in addition to wave spectra, from wave records, is also very desirable, concerning practical wave-energy conversion. The variation in offshore wave-power levels is quite large. According to Torsethaugen, there is ‘‘a factor of two between the highest and lowest yearly mean for wave energy at one particular location. The average wave energy for a winter month can be 5–10 times the mean value for a summer month. The wave energy can vary 10 times from one week to the next. The wave energy during one storm can be five times higher than the mean value for the week the storm occurs. Wave energy in wave groups can be up to 50 times the wave energy between wave groups’’. Extreme storm seas contain very much wave energy and contribute significantly to yearly mean values of wave-power level. The power-capacity limitation of a wave-power plant reduces, however, the usefulness of this extreme-state contribution. It may be said that for a wave-power plant, the income has to be provided by the prevalent moderate waves, while extreme waves may be as catastrophic as for other ocean structures. Real sea waves are composed of elementary waves propagating in different directions. Moreover, predominating wave directions are from south to west in the north and from north to west in the south of Europe. The phenomenon of wave grouping, which is important in relation to wave-energy conversion, has been addressed, recently, by Saulnier and Pontes. Because of wave groups, the available wave energy may vary significantly from one minute to the next minute.

1.2 Background and Motivation

The use of physical models in marine engineering would be limited if we were unable to create waves in small scale models that exhibited many characteristics of waves in nature. A common approach is mechanical wave generation where a movable partition is placed in the wave facility and waves are generated by oscillation of the partition.

So far most laboratory testing of floating or bottom-mounted structures and studies of wave profiles and other related phenomena have utilized wave flumes, which are usually characterized as long, narrow enclosures with a wave-maker of some kind at one end. For all these tests, the type of wave-maker is very important.

In laboratory studies, there are two main classes of mechanical type wavemakers often utilized to generate waves. The first one is the movable wall type machines including those known as piston- and paddle type wavemakers, which are generally actuated by a simple oscillatory motion in the direction of wave propagation. The second is the plunger type wavemaker, which generate waves by oscillating vertically in the water surface.

In this paper the design and construction of a small wave flume using the plunger type wavemaker, which was built and instrumented with a limited budget is described. This flume is constructed out of the need of an experimental setup for modeling waves at the fluid mechanics lab at the Islamic University of Technology. In order to design the wave flume the several reports (e.g. Khalilabadi et al 2012) were carefully reviewed. The main advantage of our system over many others is the novelty of the plunger type wavemaker and the small effort in system setup.

There are three motivations behind this project:

1. Disaster relief / Power-poverty relief.
2. Commercial applications
3. Education.

Chapter 2

Overview of the Setup

In order to achieve the intended results following design consideration was taken into account:

2.1 Channel Design

The wave flume was built for conducting laboratory tests of floating structures and validation studies in the fluid mechanics laboratory at Islamic University of Technology. This wave flume design includes a 1720 mm long, 310 mm deep and 265 mm wide channel. The dimensions are shown in Fig: 2.1. The bottom of the flume is made of the same 7-mm thick sheeting, which are held in place by Thai aluminum angle rod structural frames. The tank rests on a Thai aluminum angle bar frame base mounted on 10 mm height screws which act as legs. These screws were covered by plastic sheets of 12 mm height. The frame of the final wave flume design is sketched in Fig: 2.1. No pump or piping is provided for discharge of fluid from the flume.

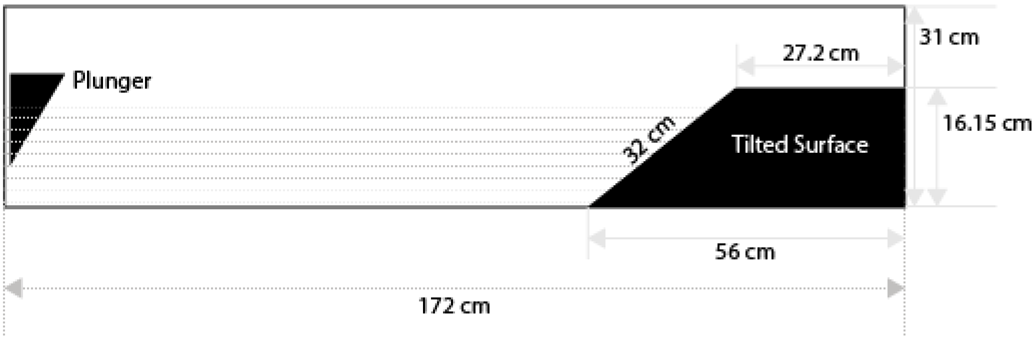

Figure 2.1: Wave Flume Schematics

2.2 Wave Maker Design

A plunger type wavemaker at one end of the tank can generate both regular and irregular waves. The plunger paddle is a triangular nylon wedge which is installed right along the end wall of the tank to minimize leaking. The dimensions of the paddle are discussed in the next section. The plunger is driven by a DC electric motor. To control the wavemaker, a variable frequency drive (VFD) is utilized which controls the motor speed by varying the motor input frequency. The installed wavemaker is capable of generating regular waves and irregular waves for a range of time periods. The wavemaker generates irregular waves by superposition of multiple sinusoidal waves with different wavelengths.

2.2.1 Wedge Dimensions

The optimum wedge dimensions were determined from the experimental work done by Rytkonen et al. on plunger type wave makers. The dimensions were based on wedge type B whose d/b ratio corresponds to 1.4.

Figure 2.2: Plunger Front View

Figure 2.3: Side View of the Experimental Setup

Figure 2.4: Motor Speed Controller

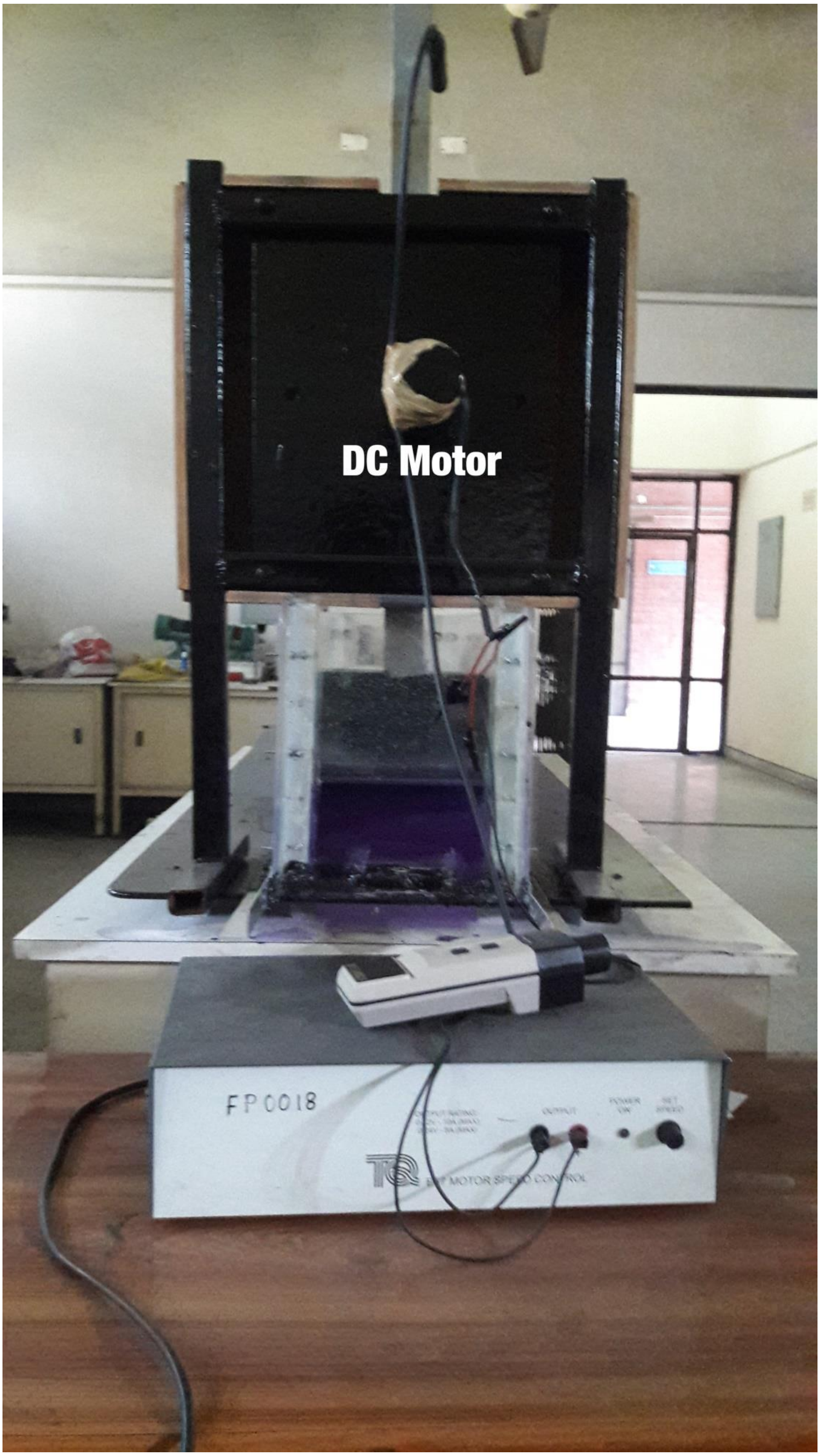

Figure 2.5: Back View of the Setup Showing DC Motor

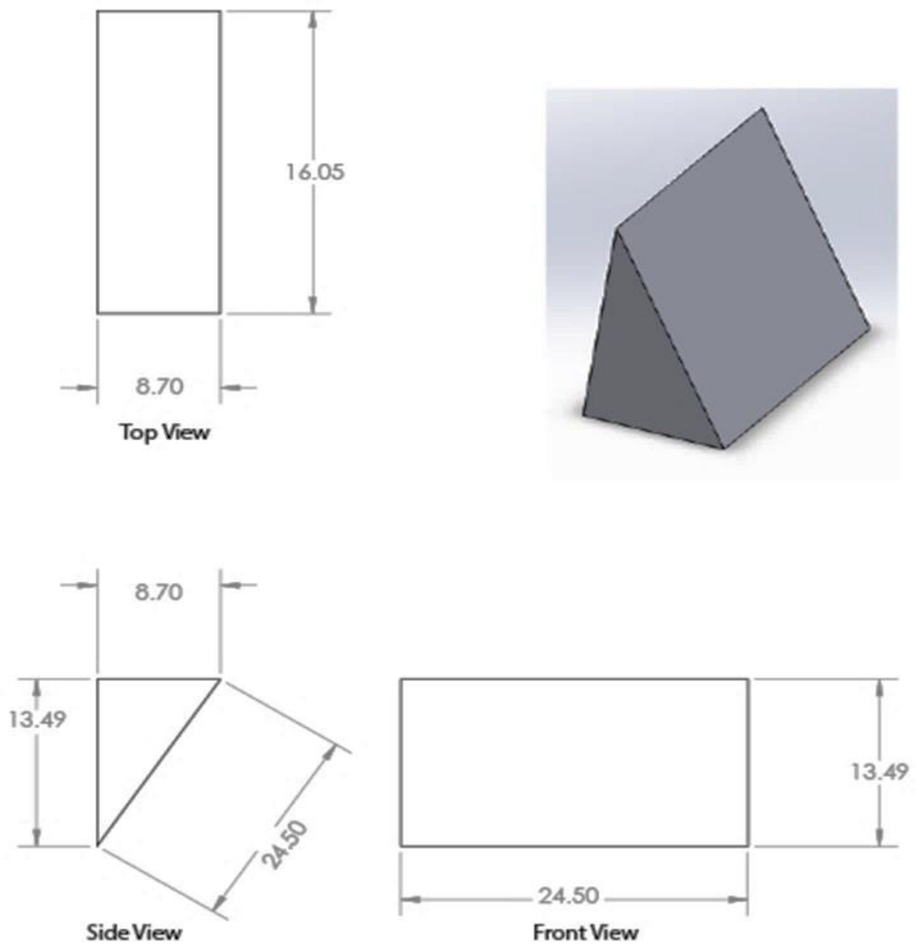

Figure 2.6: Plunger Schematics

2.3 Mechanism

The Scotch yoke mechanism is a reciprocating motion mechanism, converting the linear motion of a slider into rotational motion, or vice versa. The piston or other reciprocating part is directly coupled to a sliding yoke with a slot that engages a pin on the rotating part. In many internal combustion engines, linear motion is converted into rotational motion by means of a crankshaft, a piston and a rod that connects them. The Scotch yoke is considered to be a more efficient means of producing the rotational motion as it spends more time at the high point of its rotation than a piston and it has fewer parts. The Scotch yoke also known as slotted link mechanism is a reciprocating motion mechanism, converting the linear motion of a slider into rotational motion, or vice versa. The piston or other reciprocating part is directly coupled to a sliding yoke with a slot that engages a pin on the rotating part. The location of the piston versus time is a sine wave of constant amplitude, and constant frequency given a constant rotational speed.

Scotch Yoke mechanism is a simple type of mechanism which converts circular motion into reciprocating motion as discussed in construction part above. The power is supplied to the DC motor, shaft and crank attached to the shaft start rotating. As the crank rotates the pin slides inside the yoke and also moves the yoke forward. When the crank rotates through in clockwise direction the yoke will get a displacement in the forward direction. The maximum displacement will be equal to the length of the crank. When the crank completes the next of rotation the yoke comes back to its initial position. For the next of rotation, yoke moves in the backward direction. When the crank completes a full rotation the yoke moves back to the initial position. For a complete rotation of crank the yoke moves through a length equal to double the length of the crank. The displacement of the yoke can be controlled by varying the length of the crank.

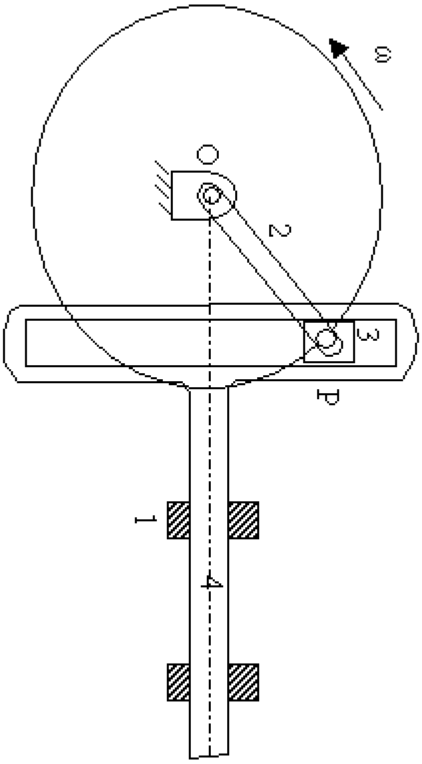

Figure 2.7: Scotch Yoke Mechanism

The main advantages of scotch yoke mechanism are

1. Direct conversion of rotary motion into reciprocating motion
2. Easy construction & operation
3. Can perform various operations such as cutting, slotting etc..
4. Process can be automated

2.4 Wave Absorber Design

After the wave generator, wave absorber is the most important part in a wave flume or basin. A great variety of designs and materials have been used throughout the world for the construction of wave absorbers. Wave absorbers could be classified into two main categories: active and passive absorbers. However the use of active absorbers owning to its high cost is still very limited, except in a few cases where the wave board itself is programmed to absorb the reflected wave. Hence passive absorbers seem to be the most popular arrangement. The slope of these absorbers has to be mild so as to obtain a good dissipation of wave energy. This usually means a long wave absorber, thus using up valuable tank space (Dalrymple et al. 2002).

In the paper by Khalilabadi et al 2012 a survey of laboratory facilities around the world was conducted in order to find an optimum wave absorber satisfying the constraints mentioned above. From 43 laboratories which investigated in this study only four laboratories use active absorbers. Most other laboratories use passive absorbers. Passive absorbers are mainly made up of beaches of constant or varying slopes. One of the important criteria to be satisfied is that the variation of the water depth over a wavelength is small, because abrupt changes of the bottom as wave absorber, 27 of them use a beach of constant slope reaching the bottom as wave absorber, 7 of them use a variation of this type of wave absorber as a mean of absorbing wave energy, 4 of them use a parabola beach reaching the tank bottom, and 3 of them use a parabola not reaching the bottom. The last two laboratories use a combination of different mechanisms to absorbers wave energy. It is clear the most wave flumes tend to use simpler types of absorber shapes.

One of the main parameters to be considered is the ratio of the absorbers length to the water depth. Most absorbers have slopes lower than 1:5. In the present work, the slope of absorber was selected 1:4 because of dimensions of the wave flume. Passive wave absorbers are placed on the basin termination opposite to the wave maker. In this case a nylon beach with a 1:4 slope is located at the end of the tank opposite to the wavemaker. This beach absorbs wave energy both by causing the incident waves to break. The beach is 560 mm and 265 mm wide.

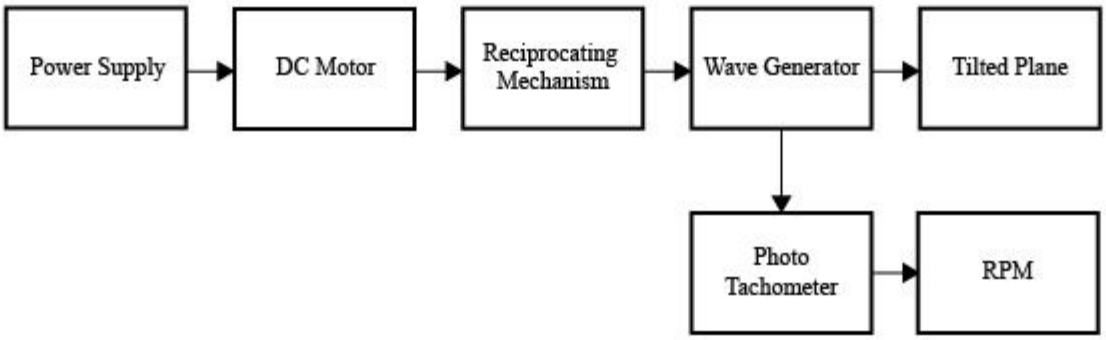

Figure 2.8: Block Diagram of the Process

2.4.1 Parts

Following are the main parts of the wave tank:

1. Center Gear
2. Spur Gears
3. Sector Gears
4. Double Rack
5. Piston Paddle
6. Base Plate
7. Inverter and Motor
8. Mild Steel Shaft
9. Collar and Bearing

2.4.2 Cost Estimation

The cost estimation for each part is summarized in Table 2.1.

Table 2.1: Cost Estimation

No.	**Part**	**Quantity**	**Material**	**Material Quantity (mm)**	**Cost (BDT)**
1	Center Gear	1	Nylon	450x150	500
2	Spur Gear	2	Nylon	450x150	500
3	Sector Gear	2	Nylon	500x250	500
4	Double Rack	1	Nylon	700x90	500
5	Piston Paddle	1	Nylon	N/A	2000
6	Base Plate	1	Steel	N/A	2000
7	Inverter and Motor	1	N/A	N/A	12000
8	Shaft	3	Aluminum	N/A	1500
9	Collar and Bearing	1	N/A	N/A	1000
	Total	13	N/A	N/A	20000

2.4.3 Parts Machining

The following steps outline the machining process of the wave flume parts:

1. Each of the three spur gears was cut from nylon sheets. Each gear has 30 teeth which were cut in a universal milling machine. All the spur gears have an outer diameter, inner diameter and pitch diameter of 123 mm, 110 mm and 116.5 mm respectively and a thickness of 12 mm. The side gears have a 23 mm diameter hole and the center gear has a 13 mm diameter hole.
2. The two sector gears were also cut from 12 mm thick nylon sheets. Two normal gears were first cut using the universal milling machine and then their teeth number was reduced to 6 using the same machine. Each sector gear has an outer diameter, inner diameter and pitch diameter of 210 mm, 190 mm and 200 mm respectively. Each has a 23 mm diameter hole in the center.
3. The double rack is 250 mm long, 43 mm wide and 12 mm thick. Each side of the double rack has 15 teeth cut into it. A 225 mm long slot runs along the middle of the rack as a part of the mechanism's locking system.
4. The base plate was cut from 12 mm thick cast iron block. The base plate dimensions are 318 mm x 400 mm x 12 mm. Three holes are drilled in the base plate to accommodate three shafts that will support the gears. A constricting pathway is placed at the bottom of the plate to limit the movement of the double rack in only one direction.
5. The plunger is a triangular wedge made out of nylon. Its dimensions have been discussed in the earlier sections.
6. Three mild steel shafts were machined in the lathe machine. They each have varying diameters along their lengths for accommodation of the plate and gears on them.

Chapter 3

Data Acquisition

Data was calculated based on several equations. And these are the instruments that were used during reading of the experiment. A photo tachometer and a variable motor speed controller.

Figure 3.1: Photo Tachometer

Figure 3.2: Motor Speed Controller

3.1.1 **Governing Equations**

The total theoretical energy generated in an ocean wave can be calculated in joules per unit of width of wave front by summing up the kinetic and potential energy together. The potential energy in a wave of length L is produced by the dislocation of the water away from the average sea level. The kinetic energy of a wave is a consequence of both horizontal and vertical water particle motions [4].

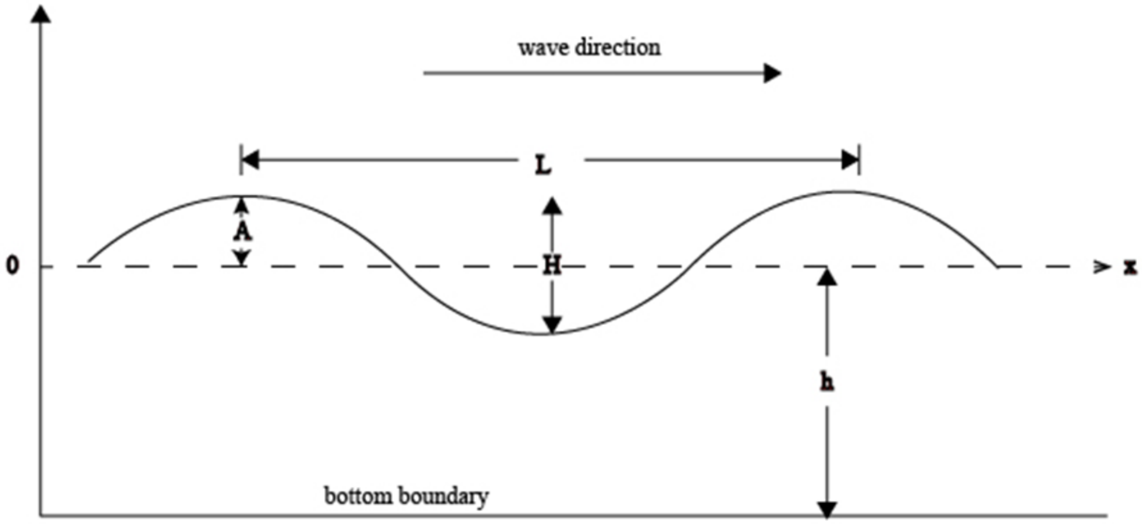

Figure 3.3: Wave Parameters

The total potential and kinetic energy of an ocean wave can be expressed as

$$E = \frac{1}{2}\rho g A^2 \qquad - (1)$$

Energy E is multiplied by the speed of wave propagation, V_g.

$$V_g = \frac{L}{2T} \qquad - (2)$$

Multiplication of equation (1) and (2) yields equation for power generated in the wave tank.

$$P_g = \frac{1}{2}\rho g A^2 \frac{L}{2T} \qquad - (3)$$

The dispersion relationship describes the connection between the wave period T and the wavelength L as

$$L = \frac{gT^2}{2\pi} \qquad - (4)$$

The power or energy flux of an ocean wave can be calculated as substituting the value of L in equation (3)

$$P_w = \frac{\rho g^2 T A^2}{8\pi} \qquad - (5)$$

Instead of using the wave amplitude, wave power can also be rewritten as a function of wave height, H. Considering that the wave amplitude is half of the wave height, the wave power becomes

$$P_w = \frac{\rho g^2 T H^2}{32\pi} \qquad \text{- (6)}$$

Above equation was used to determine the power output from the wave tank. Here ρ, g was taken as standard values. Wave height H and Time period T was taken from the experiment.

$$T = \frac{n}{t} \qquad \text{- (7)}$$

We took 5 seconds as specific time, t then number of waves was counted using burst photo mode of camera. It was noticed that for the same rpm the number of waves was same. For the highest rpm 124 we found that the number of fully generated waves was 12. So the time period, T was same for the same rpm reading.

$$T = \frac{12}{t} \qquad \text{(For 124 rpm)} \qquad \text{- (8)}$$

3.1.2 Results and Discussions:

With increment of rpm the power development is increased (fig 3.4). It was also seen that more rpm means results in higher velocity (fig 3.5). And we can also see that more rpm equals to steeper and larger wave height (fig 3.6).

Table 3.1: Effect for Constant Water Depth with Variable RPM

No	**RPM**	**Water Depth, h (cm)**	**Wave Height, H (cm)**	**Wave Length , L (cm)**	**Wave Amplitude , A (cm)**	**Wave Velocity , Vg (cm/s)**	**Time Period , T (s)**	**Power Developed , P (w/m)**
1	70	9.7	3	12	1.5	14.385	0.417	0.3592
2	110	9.7	5	25	2.5	27.775	0.450	1.0769
3	124	9.7	7	30	3.5	34.48	0.435	2.0404

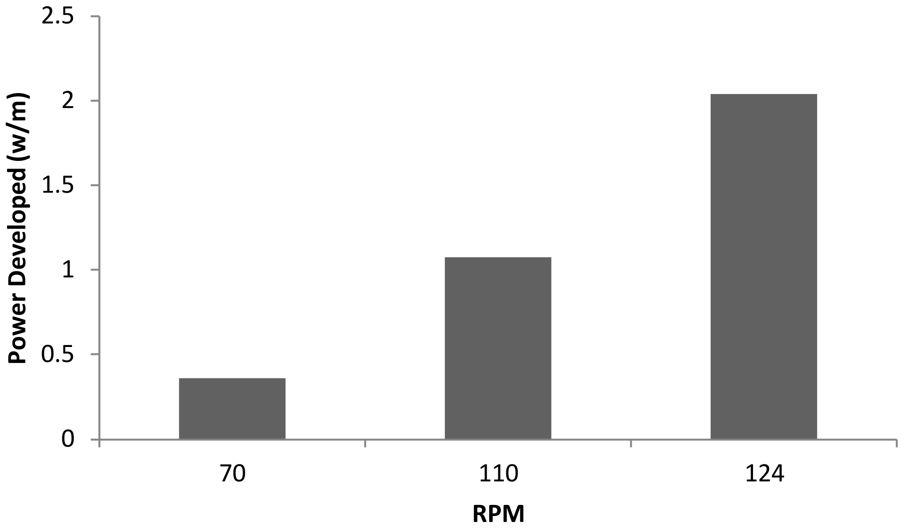

Figure 3.4: Variation of Power Developed with RPM at Constant Water Height

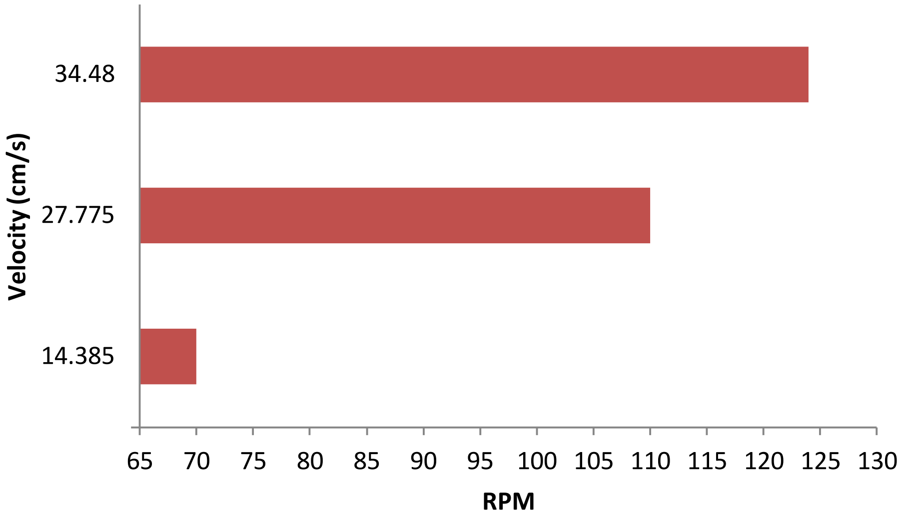

Figure 3.5: Variation of Velocity with RPM keeping Water Height Constant

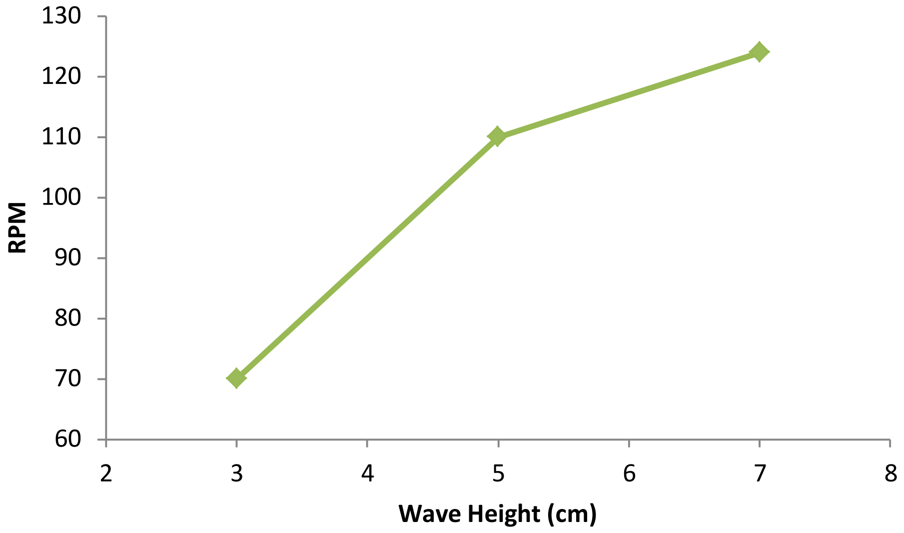

Figure 3.6: Wave Height Changes with RPM

Table 3.2: Power Developed with respect to Variable Water Depth and Constant RPM

No	**Water Depth, h (cm)**	**Wave Height, H (cm)**		**Wave Length, L (cm)**		**Wave Amplitude, A (cm)**		**Wave Phase Velocity, Vg (cm/s)**	**Time Period, T (s)**	**Power Developed, P (w/m)**	
		Near	**Far**	**Near**	**Far**	**Near**	**Far**			**Near**	**Far**
1	9.7	7	3	30	28	3.5	1.5	34.48	0.435	2.0404	0.3584
2	10.7	8	5	34	33	4	2.5	40.865	0.416	2.54	0.9955
3	11.7	9.4	4	40	37	4.7	2	48.075	0.416	3.51	0.6371
4	12.7	10	5	35	36	5	2.5	42.065	0.416	3.98	0.9955
5	13.7	9	8	37	40	4.5	4	44.47	0.416	3.22	2.5486

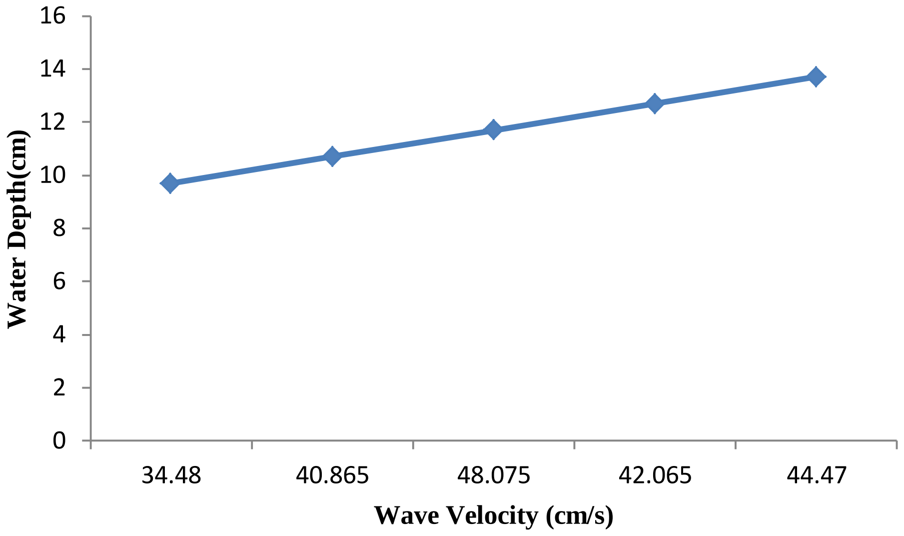

Figure 3.7: Wave Velocity Variation with Different Water Depth at Constant RPM

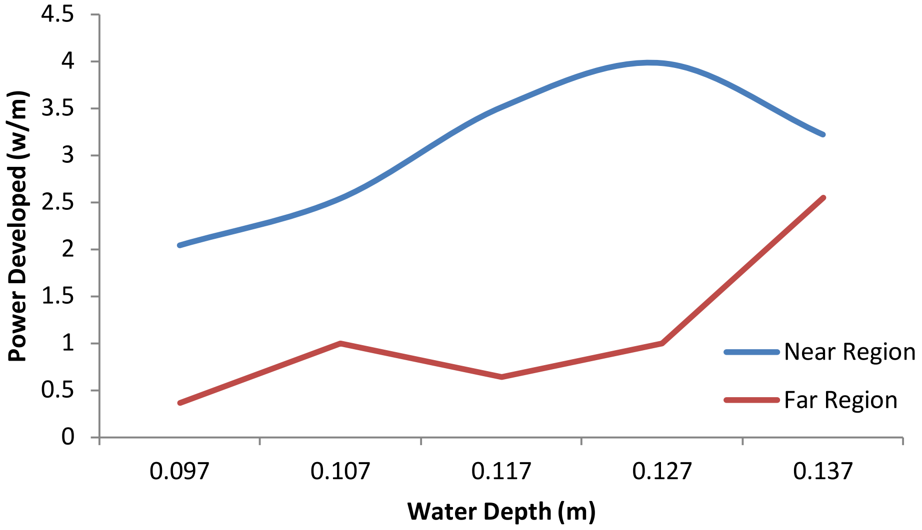

Figure 3.8: Discrepency of Power Developed with Variation of Water Depth at Constant RPM

Chapter 4

Conclusion

Crank and slider mechanism implemented on this project to generate wave energy. Variation of RPM was formed to find out different wave height, wave lengths and phase velocity. Phase velocity has been increased by the higher number of stroke.

1. Wave generated with variable RPM consisting of a constant water depth.

2. Wave generated with variable water depth providing constant RPM.

3. Lifting plunger used to generate wave.

4. Water depth, Wave height, wave lengths, amplitude had been determined.

5. Time period has also been calculated of generating wave.

6. Phase velocity has also been calculated to evaluate the developed power.

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